

# PETROGRAPHICAL STUDY OF ROCK SAMPLES FROM THE COASTAL SECTION BETWEEN TORQUAY AND AIREY'S INLET, VICTORIA

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Petrographical descriptions are given here of twenty-five specimens of sedimentary rocks which H. G. Raggatt collected from different measured sections during the preparation of the paper with Miss Crespin on "Stratigraphy of Tertiary Rocks between Torquay and Eastern View, Victoria" (1954). The sections from which the specimens were collected are given below and their exact stratigraphical position in the section can be identified by reference to that paper. All sedimentary rocks from the area have been named according to the classification drawn up by M. A. Condon (1953). The results of a rough chemical analysis made in 1947 on a sample of supposed jarosite (W.12) are given and a note on the occurrence and possible origin of the glauconite found in many of the samples, is appended.

The rocks herein described are as follows:

*Section 7—Bird Rock and adjacent Bluff*

Hard Bed 7 in, thick in BR.12,  
Bed "N" in BR.9,  
Bed "M" in BR.9,  
Bed "L" at base of BR.9,  
Bed "K" in BR.7,  
Bed "J" in BR.7,  
BR.7,  
Bed "H" in BR.6,  
Jarosite ?, Base of BR.4,  
BR.4,  
BR.5,  
BR.14,  
Hard Band in BR.14.

*Section 9—Between Fisherman's Steps and Bird Rock*

FB.4,  
FB.3.

*Section 12—Between Fisherman's Steps and Dead Man's Gully*

Bed "K",  
Bed "J",  
Bed "H",  
FD.7.

*Section 6—Rocky Point*

Bed "B" in RP.3,  
Bed "A" in RP.1.

*Section 3—Between Soapy Rocks and Point Roadknight*

W.98,  
W.12.

*Section 19—Airey's Inlet*

A.1 (2 specimens).

## SECTION 7—BIRD ROCK AND ADJACENT BLUFF

## Hard Bed 7 in. thick in BR.12

The rock is white, fairly compact, partly iron-stained and exhibits no bedding or lamination in the hand specimen. The only mineral which can be distinguished with the naked eye is mica which occurs sparingly as small flakes. The rock effervesces with cold N/10 HCl.

Under the microscope the rock is seen to consist of a finely granular mass of grey, somewhat turbid carbonate (average diameter of grains 0.01 mm.) together with foraminiferal tests, glauconite, pyrite and a little mica. The matrix may be a re-crystallized lime-mud.

Foraminiferal tests represent only 2 per cent of the rock and many of them are completely filled with glauconite. Other glauconite is not enclosed within tests, and occurs as small grains which are bounded by crystalline carbonate. The glauconite, whether free or enclosed, shows alteration to limonite.

Quartz, present as small angular grains with an average diameter of about 0.05 mm., makes up 5 per cent of the rock. Other minerals present are muscovite and biotite, as scattered small flakes, black iron ore as small grains, and limonite, mainly in form of red brown stains which impregnate the carbonate in places.

The rock is a silty calcilutite.

## Bed "N" in BR.9

This rock is fine grained, grey-white but stained pale orange in patches, slightly friable and un laminated. It effervesces only slightly with cold N/10 HCl.

In thin section, the rock is seen to consist of a finely granular mass of carbonate and angular quartz grains. The carbonate, which shows no sign of organic structure and occurs as grains with an average diameter of 0.05 mm., makes up about 90 per cent of the rock. Many of the grains are rhombs, and are probably dolomite. Quartz, angular and similar in grain size to the carbonate, makes up 5 per cent of the whole.

A few small, brownish-green, ovoid grains which appear to have aggregate polarization probably represent glauconite which has been partly converted to limonite. Other limonite stains and patches are scattered throughout the slide, and a few grains of black iron ore, a little green biotite and some colourless muscovite are also present.

This rock is a silty dolomitic limestone (calcilutite).

## Bed "M" in BR.9

This rock is grey-white and fine grained with pale red-brown patches due to the oxidation of ferrous iron. It is slightly friable and contains white foraminiferal tests which are clearly visible to the naked eye. It effervesces with cold N/10 HCl.

Under the microscope, the rock is seen to be made up of a finely-divided, grey, somewhat turbid mass of carbonate, probably with a little argillaceous matter, containing quartz grains, a few shell fragments, patches of limonite and some clearly defined foraminiferal tests. Many of the red-brown limonite patches surround a darker core which resembles a foraminifer in shape. This, together with the fact that small portions of some patches have a yellow-green tint, suggests that at least some of the limonite is secondary after glauconite.

Quartz is very angular and is made up of grains having an average diameter of the order of 0.05 mm.; these grains, with a little chalcedony and felspar, com-

prise possibly 5 per cent of the rock. Also present are a few grains of black iron ore and flakes of muscovite.

This rock is a silty calcilutite.

#### Bed "L" at base BR.19

The rock is white, stained orange by iron oxide. It is fairly friable, fine-grained and contains a few shell fragments. It effervesces slightly with cold N/10 HCl.

Under the microscope, the rock consists of a grey, turbid mass of finely-divided carbonate, slightly iron stained in patches, containing angular quartz grains, foraminiferal tests and a few shell fragments. Organic remains form less than 3 per cent of the whole. The tests contain material, apparently mostly of clay with a little carbonate which has been stained brown—this stain commonly extends beyond the walls of the tests to form irregular patches in the surrounding rock. Other brownish patches, which in places have cores of green, chloritic or glauconitic material, are scattered throughout the rock; some of these appear not to have been enclosed in foraminifera.

Quartz grains, which are angular and have an average diameter of 0.05 mm., make up 20 per cent of the rock. A little muscovite and a few small grains of black iron ore are the only other minerals present.

This rock is a silty, calcareous claystone.

#### Bed "K" in BR.7

The rock is grey, with large red-brown patches due to iron staining, and is fairly friable, with no discernible bedding. It effervesces with cold N/10 HCl.

Microscopically, the rock consists mainly of granular carbonate having no obvious organic structure and an average grain diameter of 0.05 mm. Quartz, which is markedly angular, makes up only 1 per cent of the rock. Other minerals present in small quantity are black iron ore, pyrite, limonite, and little clay, and a few grains of a green mineral, probably glauconite.

The rock is calcilutite.

#### Bed "J" in BR.7

This rock is grey, somewhat friable and shows no lamination in hand specimen and contains white shell fragments. It effervesces with cold N/10 HCl.

Microscopically, the rock consists of carbonate (82 per cent), quartz grains (15 per cent), and pyrite (3 per cent). The carbonate is colourless, cloudy or brown—some of the brown material obviously has an immediate organic origin and is present in form of shell fragments and broken foraminiferal tests; but most of the carbonate is finely granular perhaps from re-crystallization of lime-mud. The quartz grains, which are angular, exhibit remarkable uniformity of size (average diameter 0.06 mm.). Pyrite is scattered throughout the carbonate as small irregular grains. Also present are a little green chloritic material, a few flakes of brown biotite and some angular grains of sodic plagioclase.

The rock is a silty calcilutite.

#### BR.7

This rock is grey and very friable, and shows no bedding or lamination in the hand specimen. Small shell fragments, tiny specks of mica and a little pyrite can be seen in the fine grey base which is apparently partly calcareous and partly argillaceous. The rock effervesces with cold N/10 HCl.

In thin section the rock is seen to be made up of a yellow-brown base, organic remains, quartz, pyrite and glauconite. Most organic remains consist of broken



foraminiferal tests—usually of colourless to somewhat turbid carbonate, and a few consist of elongate or irregularly shaped, brown, turbid fragments derived from larger organisms. The yellow-brown base is very fine and is difficult to resolve into its components under the microscope—it seems to be made up mainly of argillaceous material, fine quartz, black iron ore and pyrite, mica and possibly feldspar. Some finely disseminated carbonate is probably present. Green glauconite, with aggregate polarization, is scattered rather sparingly throughout the slide in the form of ovoid pellets. Rare grains of glauconite which seem to grade into the yellow-brown material are also present—these are not well defined and appear in places as small greenish patches. Foraminifera are numerous, but none in this slide seems to contain glauconite.

Angular quartz is fairly abundant as grains with an average diameter of 0.08 mm. Mica consists mainly of muscovite, green biotite and a few flakes of brown biotite. A little chlorite may be present, but this is difficult to distinguish from the small green glauconite patches. The only other mineral noted consists of a rare grain of brown tourmaline.

The estimated composition of the rock is as follows:

Yellow-brown base .. .. .	41%
Carbonate .. .. .	33%
Quartz .. .. .	22%
Pyrite .. .. .	3%
Mica, glauconite .. .. .	1%

This rock is a sandy foraminiferal marl.

#### Bed "H" in BR.6

This rock is grey, silty, and fairly well consolidated, with no evidence of bedding or lamination in the hand specimen. It effervesces slightly with cold N/10 HCl.

In thin section, this rock is seen to consist mainly of even-grained crystalline carbonate (average diameter 0.05 mm.) together with lesser amounts of quartz, marcasite, glauconite and mica. Foraminifera are present, but nearly all of the carbonate, which constitutes about 87 per cent of the slide, shows no evidence of immediate organic origin. Some of the foraminiferal tests enclose marcasite and a little dark red iron ore, probably haematite—none in this slide encloses glauconite. The origin of the small ovoid grains of glauconite which are present is uncertain—they may have been derived from mica, which is scattered sparingly through the section in the form of green and brown biotite flakes. Nevertheless, a careful search of the slide failed to reveal any mica which is partly changed to glauconite, and there is thus no direct evidence of such a transformation. Tiny patches of what appears to be argillaceous material are scattered sparingly through the rock, but no gradation of these into glauconite was noted.

Many of the aggregates of iron ore (probably marcasite) are composed of grains with a radiating structure, and many of the grains are partly surrounded by faint brown stains of ferric iron. Quartz is present as clear angular grains which form possibly 8 per cent of the whole. The only other mineral noted is an occasional grain of leucosene.

This rock is a silty crystalline limestone or calcilutite.

#### Jarosite ?, Base of BR.4

In the hand specimen this rock is soft and friable, and is made up of a pale yellow mineral (which comprises apparently 60 per cent of the whole) black pyrite

and a few grains of a lighter coloured material. The rock does not effervesce with acid.

Microscopically, about 40 per cent of the rock consists of a mineral which has been so impregnated and stained with limonite that it appears opaque and red-brown in reflected light. In places, where limonite staining is not pronounced, the mineral is translucent—it appears yellowish in colour, with high relief, strong birefringence and aggregate Polarization. This mineral may be jarosite, or some mineral closely related to it, but the degree of impregnation with limonite which it has undergone renders microscopic identification uncertain.

Large crystals, many of them of a colourless mineral with weak birefringence and low relief, make up possibly 50 per cent of the rock. This mineral may exhibit multiple twinning, has good cleavage in one direction, and is interleaved with a pale grey or neutral mineral with higher birefringence. The optical properties of the colourless mineral are as follows:

Elongation—negative.

2V—positive, about  $65^{\circ}$

R.I.—1.518-1.529 as nearly as can be determined.

These properties show that the colourless mineral is gypsum. Some crystals have a diameter of up to 4 mm; other smaller, perfectly euhedral, crystals are completely enclosed by the mineral, impregnated with limonite.

Associated closely with the gypsum is a pale, colourless to grey flaky mineral with moderate birefringence and relief greater than balsam. This mineral is uniaxial or nearly so, and is optically negative. The extinction of most but not all of these flakes is parallel and the elongation is positive. The mineral is probably alunite. It appears to occur in close association with the gypsum crystals.

About 10 per cent of the rock is made up of pyrite. This is in form of aggregates, many of which have linear borders that seem to have been determined in some measure by the crystallizing power of the gypsum.

This rock is a weathered alunite jarosite (?), gypsum rock.

#### BR.4

The rock is light grey, argillaceous and friable, with no visible lamination in the hand specimen. It contains occasional fragments of bryozoa and shells together with foraminifera, quartz and a small amount of mica and green glauconite. The rock effervesces with cold N/10 HCl.

Under the microscope, this rock is seen to consist mainly of foraminiferal tests, fragments of hard parts of larger organisms and quartz grains. Also present are pyrite, glauconite, mica, a few sponge spicules and a brownish, earthy base which is difficult to resolve but apparently consists of a very finely-divided quartz, mica, carbonate and clay.

Many of the large carbonate fragments are pale brown and turbid and are probably partly altered to collophane; the abundant foraminiferal tests, some of which are turbid, are generally somewhat clearer in appearance. The outlines of many foraminiferal tests are well defined, and these can be clearly seen acting as hosts to glauconite. In many tests each chamber of the foraminifera is completely filled with green glauconite. Possibly between 5 and 10 per cent of the tests are so filled; the remainder are empty or contain a filler of pale brown, earthy material that shades into pale green. Glauconite was seen which is not enclosed by foraminiferal tests—this seems to grade from dark green glauconite proper to pale brownish material with a greenish tint.

A small proportion—less than 1 per cent of the rock—is made up of pyrite. In some places this mineral partly or wholly fills the chambers of foraminifera, and in other parts of the slide it occurs as isolated grains. Quartz as angular grains with a diameter of 0·05 mm., and a little feldspar, probably orthoclase, are the only other minerals present.

The rock is made up in the following proportions: carbonate 68 per cent, pale brown earthy material 21 per cent, quartz 7 per cent, glauconite 2 per cent, pyrite 1 per cent, feldspar and mica 1 per cent.

This rock is a silty argillaceous calcarenite.

#### BR.5

This rock, which is grey and very friable, is made up of shell fragments and tiny foraminiferal tests with a little green glauconite and a few specks of mica. It exhibits no bedding or lamination in the hand specimen. It effervesces with cold N/10 HCl.

Under the microscope, this rock is seen to be composed mainly of foraminiferal tests and other calcareous fragments, angular quartz grains (average diameter 0·06 mm.), argillaceous material, some glauconite, and pyrite. Many of the foraminiferal tests have been well preserved and stand out clearly in thin section; the carbonate of which they are composed is grey and turbid. Other irregularly shaped fragments which range in colour from grey to brown have been determined as the broken portions of shells and echinoid spines. A few colourless sponge spicules are also present. Brown fragments may have been changed from carbonate to collophane. Many, but not all, foraminifera contain glauconite; on the other hand, some glauconite can be seen which does not appear to have been enclosed within an organic structure. A few small grains of pyrite can be seen, often concentrated within a foraminiferal test. Carbonate (including collophane) makes up 68 per cent of the whole, quartz about 30 per cent, and glauconite 2 per cent.

This rock is a silty, argillaceous calcarenite.

#### BR.14

In the hand specimen the rock is grey and friable; foraminifera, flakes of mica and a little black pyrite are clearly visible in an argillaceous base. The rock is not laminated. It effervesces with cold N/10 HCl.

In thin section, this rock is seen to be composed of a base of pale grey-brown material, quartz grains and foraminiferal remains, together with some glauconite, biotite and other minerals. The grey-brown base, as far as can be determined, is made up of argillaceous material, finely-divided quartz, tiny flakes of mica, a little feldspar and possibly carbonate; small grains of black iron ore are scattered throughout. In one part of the section the base takes the form of ovoid pellets, whose large and small diameters average respectively 0·28 and 0·15 mm. As the pellets are slightly deeper coloured round the margin than towards the centre, and may be cemented locally by iron ore, their outlines are in places very clearly defined. Some of the pellets contain aggregates of a mineral with low relief and low birefringence which has a radial structure—this is probably chalcedony. It seems likely that these pellets may be a variety of coprolite.

Glauconite is not abundant. Some of it is enclosed within the tests of foraminifera, but much of it shows no trace of any enclosing organism. Not all foraminifera contain glauconite—some appear empty and others contain finely-divided carbonate and argillaceous material. A few small grains of green glauconite can



be observed whose boundaries, even under a magnification of 450, merge imperceptibly into the surrounding argillaceous matrix; this suggests derivation of the glauconite from the finely-divided base. There is a fair abundance of green biotite scattered throughout the slide, but a careful search has failed to reveal any biotite which is definitely in the process of alteration to glauconite.

Angular quartz grains of average diameter 0.05 mm. make up 12 per cent of the rock. Pyrite is fairly abundant—it constitutes perhaps 3 per cent of the whole and occurs as a local cement between coprolite pellets, and as small grains scattered throughout the slide. A few foraminifera are replaced by pyrite. A little black iron ore and some red-brown iron stains are also present.

This rock is a silty, foraminiferal and coprolitic marl.

#### Hard Band in BR.14

This rock is grey-white and compact, and contains numerous white shell fragments and foraminiferal tests, together with a little green glauconite. It effervesces slightly with N/10 HCl.

Under the microscope, this rock is seen to consist mainly of carbonate made up of fragments of foraminifera and bryozoa and other organic remains in a finely granular, carbonate cement. Most of the organic detritus is slightly turbid and a little is converted to pale brown collophane.

Glauconite, as green ovoid grains, many of which are clearly enclosed within foraminifera, makes up about 1 per cent of the whole. Angular quartz grains, of average diameter 0.1 mm., also make up 1 per cent.

Other minerals present are a few grains of pyrite, a little kaolin and limonite, and some small grains of a brown mineral with high relief and high birefringence, which may be sphene.

The rock is a calcarenite.

#### SECTION 9—BETWEEN FISHERMAN'S STEPS AND BIRD ROCK

##### FB/4

The rock is grey and friable, and contains small gastropods, foraminiferal tests, green glauconite pellets, a few small quartz grains and some specks of mica. The specimen contains a few very small red-brown patches of limonite, and exhibits no bedding or lamination. It effervesces with cold N/10 HCl.

Under the microscope this rock is seen to consist mainly of carbonate—made up chiefly of shell fragments and foraminiferal tests—together with smaller amounts of glauconite, pyrite, limonite and muscovite. Some of the material of which the foraminiferal tests and shell fragments are composed is grey and turbid though some is pale brown where converted to collophane. A pale grey base, made up probably of very finely-divided mica, carbonate, quartz and clay with limonite and pyrite specks scattered throughout, comprises 15 to 20 per cent of the whole.

Glauconite forms 1 per cent of the rock and much of it is enclosed within foraminiferal tests, many of which have their walls pressed apart or broken. Many grains of glauconite have no enclosing test walls, and careful examination of them has failed to reveal even small portions of test wall fragments. A few small grains when examined under high power magnification (x450) seem to consist of green glauconite cores which merge gradually into the grey argillaceous base. This suggests derivation of at least some of the glauconite from the base. Other grains with fairly well defined boundaries resemble in shape many of the mica flakes which are present. This resemblance is fairly strong where the mineral has the

rough or slightly mammilated surface of glauconite and has practically no double refraction. No definite example of the conversion of biotite can be seen, i.e. there seems to be no example of a grain which is part biotite, part glauconite. This may perhaps be due to the fact that the biotite is green, making any alteration to green glauconite, if present, particularly difficult to recognize in small flakes. Much of the glauconite contains small flakes of mica and tiny quartz grains which could indicate either derivation from the finely divided matrix, or derivation from glauconite which expanded during the process, absorbing surrounding elastics.

An opaque mineral with a metallic lustre and bronze-yellow colour in reflected light which occurs as irregular grains commonly with a radial structure, is probably marcasite. One marcasite aggregate is enclosed within the test of a foraminifera, and some foraminifera and shell fragments have been replaced by the mineral. Almost without exception, marcasite is surrounded by an aureole of red-brown material, apparently carbonate which has been discoloured by iron-rich solutions derived from the marcasite.

Small specks of haematite, making up about 2 per cent of the rock, are scattered uniformly throughout the slide. Angular quartz with an average diameter of only 0.02 mm. represents probably less than 1 per cent. A few small black iron ore grains, occasional flakes of biotite and a little felspar comprise the only other minerals present.

The rock is a silty calcarenite.

### FB.3

This rock is medium grained, very friable and light grey. It is made up mainly of shell fragments, foraminiferal tests and quartz grains, with occasional small greenish patches of glauconite. This rock effervesces with cold N/10 HCl.

Under the microscope the rock is seen to consist essentially of grey turbid carbonate probably derived from pre-existing limestone, foraminiferal tests and other organisms, patches of grey-brown, finely-divided cement, angular quartz fragments and pellets of glauconite. The grey-brown matrix, which comprises possibly 7 per cent of the rock, is made up of clay, finely-divided quartz, minute mica flakes and carbonate, the whole cement stained lightly with red-brown iron oxide. Some small irregular patches of pale yellow-green glauconite are scattered throughout the matrix, into which they seem to grade imperceptibly, suggesting they have been derived directly from it. Other glauconite is found as ovoid pellets with a long diameter of up to 1 mm. and a short diameter of up to 0.6 mm. A little glauconite is found in the skeletons of bryozoa and the tests of foraminifera. This glauconite may occupy all chambers of the foraminiferal test, or only the outer chambers. The walls of some of the tests that contain glauconite have been pressed apart, suggesting that larger grains may once have been similarly encased. However, careful examination of many of these grains has revealed no evidence of fragmentary test walls. The glauconite of this rock ranges in colour between yellow-green and dark yellow-green—probably all varieties show aggregate polarization but this is difficult to see where the birefringence is very low. Double refraction seems to range between very low and fair (apparently second order) but is generally hard to determine because of the masking effect of the colour of the material. Glauconite makes up 2 per cent of the whole.

Angular quartz makes up about 5 per cent of the rock—grains are fairly large and have an average diameter of 0.5 mm.

The rock is a sandy argillaceous calcarenite.



## SECTION 12—BETWEEN FISHERMAN'S STEPS AND DEAD MAN'S GULLY

## Bed "K"

This rock consists of a white, friable mass of carbonate, iron-stained in patches, which effervesces with cold N/10 HCl.

In thin section, the rock is seen to consist of finely-divided, grey matrix (which is red-brown in places due to iron staining) and angular quartz grains. The matrix may owe its grey colour to the presence of argillaceous impurities and makes up 93 per cent of the rock; quartz grains, with an average diameter of 0.04 mm., make up 3 per cent. No recognizable organic remains are present in this section, the only constituents being feldspar, a little chlorite and a few grains of black iron ore.

The rock is a silty marl.

## Bed "J"

This rock is grey in patches, but is generally red-brown due to oxidation of the iron content. It is fine-grained, slightly friable, and effervesces slightly with cold N/10 HCl.

Microscopically this rock consists of an iron-stained mass of finely-divided carbonate, probably associated with clay, together with quartz grains and foraminiferal tests. Iron-stained material makes up 80 per cent of the rock; in some places the staining is concentrated in cores which are entirely opaque and are red in reflected light—these cores probably represent haematite. Quartz, as clear, angular grains with an average diameter of 0.04 mm., and a little feldspar, constitute 19 per cent of the whole.

A few small patches of glauconite, enclosed within foraminiferal tests, can be seen—other minerals present include muscovite, brown biotite, black iron ore and one grain of tourmaline.

The rock is a silty marl.

## Bed "H"

In the hand specimen, the rock is grey, silty and non-friable; on broken surfaces black dendritic aggregates of pyrite are visible. The rock effervesces slightly in cold N/10 HCl.

Under the microscope, the rock is seen to consist of very finely crystalline, somewhat turbid mass of carbonate containing angular quartz grains. Carbonate forms possibly 82 per cent of the whole; quartz grains which have an average diameter of only 0.04 mm. make up about 9 per cent. Pyrite occurs as small grains and dendritic aggregates, many of which are surrounded by an aureole of red-brown iron stains. Pyrite constitutes 8 per cent of the rock. The remainder is made up of a few plagioclase grains, patches of brownish material which are difficult to resolve under the microscope but which seem to consist of chlorite and clay, and rare grains of zircon. One carbonate fragment which probably represents a foraminiferal test, is present.

The rock is a silty calcilutite.

## FD.7

In the hand specimen this rock is grey with iron-stained patches; it is aphanitic, fairly friable, and effervesces with cold N/10 HCl.

In thin section the rock is seen to be made up of finely granular, even-grained carbonate with no obvious organic structure, and an average grain diameter of 0.04 mm. Carbonate forms 95 per cent of the rock; angular quartz makes up 3 per cent. A few grains of green glauconitic material, a little pyrite, haematite and leucoxene,

and some small, indefinite patches of brownish material, make up the remainder of the rock. Most haematite grains are surrounded by small red-brown areas of stained carbonate.

The rock is an aphanitic crystalline limestone or calcilutite.

#### Bed "B" in RP.3

In the hand specimen, this rock appears pale orange-brown due to uniform staining by iron oxide; it is fine-grained, slightly porous, non-friable and is not laminated. It effervesces with cold N/10 HCl. Tiny foraminiferal tests can be seen with difficulty by the naked eye.

Under the microscope, 94 per cent of the rock is seen to be composed of grey, partly iron-stained carbonate; the carbonate is made up of the calcareous skeletons of various organisms including the tests of foraminifera. Some poorly defined patches of turbid grey-brown material within the tests, which cannot be resolved under the microscope, probably represent lithified mud. This material in places has a pale dirty green colour, and is presumably the precursor of glauconite.

Glauconite, together with secondary limonite, forms 5 per cent of the rock. This mineral seems to be almost invariably enclosed within a foraminiferal test, or within the pores of some organic skeletal remains. All stages can be seen in the conversion of glauconite to limonite, as follows:

- (1) Pale yellow-green glauconite with aggregate polarisation.
- (2) A greenish, brown mineral with masked polarisation colours. This mineral appears dull red-brown in reflected light.
- (3) An opaque mineral which is red-brown in reflected light-limonite.

In places tiny grains of pyrite are associated with the glauconite.

Quartz is sparsely distributed throughout the rock in angular grains with an average diameter of only 0.05 mm.—this contrasts with the foraminifera which range up to 0.5 mm. and average about 0.3 mm. Quartz comprises probably less than 1 per cent of the whole.

This rock is a glauconitic calcarenite.

#### Bed "A" in RP.1

The rock is grey, slightly iron-stained in places and somewhat friable. It shows no trace of bedding or lamination. Green glauconite, quartz grains and foraminiferal remains can be seen with the naked eye. The specimen effervesces with cold N/10 HCl.

Under the microscope, this rock appears somewhat coarser than those described previously. It consists mainly of carbonate (95 per cent) and angular quartz grains. The carbonate is generally grey and turbid, and is made up of broken fragments perhaps of pre-existing limestone, many with good cleavage, and abundant clearly defined foraminiferal tests. Irregular clots of a yellowish-green mineral with aggregate polarisation, which is partly converted to limonite, represent glauconite. These make up about 1 per cent of the rock, and are usually found enclosed in foraminiferal tests. A few patches of grey-green material which are difficult to resolve under the microscope, probably consist of finely divided carbonate, clay and mica.

The quartz grains, which are notably angular, have an average diameter of 1 mm.; innumerable small cavities, generally less than 0.01 mm. in diameter, are present. These cavities contain a gas-liquid mixture, the fluid nature of which is clearly demonstrated by small bubbles which can be seen moving from side to side of their enclosure.

This rock is a calcarenite.

## SECTION 3—BETWEEN SOAPY ROCKS AND POINT ROADKNIGHT, ANGLESEA

## W.98

The rock has a grey, slightly vesicular matrix containing angular fragments of white or pale green, cryptocrystalline shards and larger fragments which are embedded in a brown, amorphous, isotropic matrix. The brown matrix probably represents a mixture of ash, argillaceous matter and glassy material; it commonly contains angular fragments of quartz up to 0.1 mm. in diameter and crystallites of plagioclase.

The pale, cloudy, cryptocrystalline fragments in some cases contain numerous incipient plagioclase crystals, which may be arranged either as a network, or in a linear manner suggestive of flow structure. Other fragments contain aggregates of larger, euhedral to subhedral plagioclase crystals which may attain a length of 2 mm.—this plagioclase is usually of the variety labradorite. Spherulitic aggregates of chalcedony are also present in a few places. The larger cryptocrystalline masses and shards are commonly surrounded by a brown aureole which is appreciably darker than the majority of the brown matrix.

Also present in the rock are a few small grains of a green non-pleochroic mineral which is either isotropic or weakly double-refracting. Grains of black iron ore and rare pyrite are scattered throughout.

This rock is a fine volcanic breccia containing mud fragments.

## W.12

A sample of a soft yellow mineral (W.12) thought to be jarosite, was roughly analysed in 1947 by E. R. Segnit of the Cement Section, C.S.I.R.O., Fisherman's Bend, Melbourne. His results are as follow:

SiO <sub>2</sub>	..	..	..	..	..	23.9
Fe <sub>2</sub> O <sub>3</sub>	..	..	..	..	..	16.5
Al <sub>2</sub> O <sub>3</sub>	..	..	..	..	..	6.2
CaO	..	..	..	..	..	0.9
MgO	..	..	..	..	..	n.d
H <sub>2</sub> O at 113	..	..	..	..	..	16.3
H <sub>2</sub> O at 113	..	..	..	..	..	7.5
Na <sub>2</sub> O	..	..	..	..	..	5.1
K <sub>2</sub> O	..	..	..	..	..	nil
SO <sub>3</sub>	..	..	..	..	..	21.1
						<hr/> 97.5

Insoluble matter .. .. 26.9%

In explanation of his results, Segnit states that the mineral appears to be natro-jarosite, mixed with earthy matter. He thinks the lime may be present as carbonate, and that the result for sulphate may be too low. No potash could be detected with the flame photometer. The insoluble residue is considered to be chiefly quartz.

## SECTION 19—AIREY'S INLET

## A.1 (Specimen 1)

In the hand specimen the rock has an overall grey-green colour; it is slightly friable, fairly weathered and somewhat vesicular. Few serpentinous relicts of olivine phenocrysts together with abundant white, angular grains of tridymite are set in the dark, fine-grained groundmass. This sample is in the form of a small cobble, and apparently forms part of a volcanic agglomerate—a small portion of the grey matrix of the agglomerate is attached to the cobble.



Under the microscope, the rock is porphyritic with completely altered olivine phenocrysts of average diameter 1 mm. in a fine-grained groundmass. Tridymite is abundant as a colourless, clear mineral which apparently occupies cavities within the rock.

The presence of olivine phenocrysts in the original rock can be inferred from the characteristic, generally euhedral serpentinous pseudomorphs which can be seen. The serpentine, which ranges from reddish-yellow to yellow-green, is made up of two varieties. One variety, the commoner, is lamellar and non-fibrous and probably represents bowlingite; the other occurs as cross-fibre veinlets with pronounced pleochroism from pale green to darker yellow-green or brown—this is probably xylotile. The two minerals are intimately associated. In places, however, the phenocrysts have altered to pale green antigorite.

The groundmass consists essentially of plagioclase, pyroxene and serpentine. Plagioclase occurs as a network of lathes having a composition which may be designated  $\text{Ab}_{38}\text{An}_{62}$ .

The average length of these lathes is 0.1 mm. Pyroxene is present as smaller, subhedral, purplish, faintly pleochroic grains which strongly resemble titan-augite and show incipient alteration to pale green bastite. Black iron ore occurs as minute grains and locally as a network of minute lathes. No volcanic glass can be seen, but this may have been the precursor of much of the abundant, pale-green serpentine (probably antigorite) which fills the interstices between the felspar lathes.

Tridymite, which seems to occupy cavities in the groundmass, occurs as angular aggregates; many of these have irregular outlines but are oval in general shape. The maximum diameter of these aggregates commonly approaches 2 mm. The mineral is colourless, has poor relief with  $n=\text{balsam}$ , very low birefringence and is characterized by abundant wedge-shaped twins. Some of the aggregates have a tile structure when observed under crossed nicols. Interference figures can be obtained on some of the larger crystals, and indicate a positive 2V of  $30^\circ$  to  $40^\circ$ .

The composition of the rock, estimated visually, is as follows:

Groundmass .. .. .	75%
(Serpentine, 39%; plagioclase, 16%)	
(augite, 10%; magnetite, 10%)	
Tridymite .. .. .	22%
Serpentine pseudomorphs after olivine ..	3%

The rock is a serpentinised olivine basalt containing pockets of tridymite, probably as fillings of what were once vesicles. The specimen consists of a small cobble embedded in the matrix of a volcanic agglomerate.

#### A.1 (Specimen 2)

The hand specimen is grey, friable and un laminated; it consists mainly of soft, pale brown or grey material together with chalcedony and opal. The rock is apparently the tuffaceous matrix of a volcanic agglomerate.

This rock, which is light grey in the hand specimen, assumes an overall greenish colour when cooked in balsam preparatory to making a thin section. Under the microscope, it is seen to consist mainly of fairly uniform, green, non-pleochroic material which is isotropic or weakly double refracting, and has a low relief with  $n$  slightly greater than balsam. The material shows its greatest tendency towards weak double refraction in places where the colour is very pale green or yellowish. It is not certain what the green matrix of this rock represents; it may be a variety of the mineraloid palagonite, which is a hydrogel formed by the alteration of basaltic glass.

Numerous spherulites, generally outlined by a brown or green border, and commonly elongated in a constant direction, are scattered through the rock. The spherulites seem to be composed of two minerals. One variety consists of a colourless fibrous mineral with low relief and weak double refraction which resembles chalcedony, and the other variety is made up radiating fibres of a brown pleochroic mineral with fair birefringence which may be the serpentine xylotile. A few chalcedonic spherulites attain a diameter of 0.6 mm.

Remnants of euhedral crystals, probably of some ferromagnesian mineral, are present; these are entirely replaced by brown, pleochroic, radial aggregates of xylotile. Chalcedony and opal are common and make up probably 15 per cent of the slide. The chalcedony, which is colourless, occurs in what appear to be colloform crusts which have been infilled with grey, isotropic opal. Euhedral to subhedral crystals of labradorite attain in places a length of 0.5 mm. and are present either as aggregates or individuals.

The rock is the matrix of a volcanic agglomerate.

### Note on the Origin of Glauconite in the Jan Juc Formation

In thin section, glauconite from the Janjukian type section of Victoria ranges from pale yellow-green to almost apple-green; it has aggregate polarisation, and its birefringence is generally masked by the original colour of the grain. Pellets and grains of the mineral are commonly heterogeneous, and may contain fragments of quartz, mica and various iron ores. The heterogeneous nature of the glauconite, together with its aggregate polarisation, have made almost impossible an accurate determination of the three refractive indices which, however, lie between 1.575 and 1.603. These figures are lower than those usually quoted (Winchell, 1946; and Schneider, 1927), and fall between those given for the Lakes Entrance glauconite and the low index glauconite from South Australia (Dallwitz, 1948).

Glauconite from the Janjukian samples is not constant in optical character, but apparently represents stages in the transformation of some pre-glauconitic progenitor to true glauconite. All glauconitic materials show a marked tendency to alteration to limonite, and the following stages can be seen:

- (1) Green glauconite with aggregate polarisation.
- (2) A brown mineral with a greenish tint, which has strongly masked birefringence. This mineral appears dull red-brown in reflected light.
- (3) An opaque mineral-limonite which is red-brown in reflected light and which may be surrounded by stains of similar colour.

Glauconite from these samples may be broadly divided into two classes as follows:

- (1) Glauconite which is enclosed within the tests of foraminifera, or within cavities in other organisms with hard skeletons, or glauconite which was once clearly enclosed by some organic covering. The glauconite may completely fill each chamber of a foraminifera, or may occupy only the outer chambers. Many foraminifera containing glauconite appear in thin section as completely preserved and well-defined tests, where others are represented by fragments of broken test walls.
- (2) Glauconite grains which are not enclosed within the hard framework of any organism, and some which may not have been enclosed during any stage of its formation. In this category is included glauconite as oval pellets, glauconite with fairly irregular shape but clearly defined boundaries, and glauconite with indefinite boundaries which seem to grade

imperceptibly into the surrounding argillaceous material. This latter, poorly defined glauconite, usually occurs as small patches which are scattered rather sparingly through the rock; they are best observed and described under high magnification ( $\times 450$ ).

Galliher (1935) has shown conclusively that glauconite in Monterey Bay, California, has formed from brown and green biotite. Glauconite forms around the edges of the flake, and by working in toward the centre, slowly converts the whole biotite grain. It also attacks biotite along the cleavage, causing the flakes to split slowly apart. With glauconitization comes a great increase in volume, so that, as the flakes are pushed apart, the whole grain assumes a "concertina" structure. Of 800-1,000 grains which Galliher described from Monterey Bay, he noted only one which was enclosed within a foraminifera.

Shepard (1948), noting that glauconite is an indicator of slow deposition, states that, whatever its origin, it is quite certainly an indication of the failure of sediments to cover the deposit during the time of their alteration. As the mineral is found in abundance in the tests of foraminifera, he is inclined to the view that biotite may not be its most important source. Both Shepard and Galliher refer to the pioneer work of Murray and Renard (1891), who emphasized the importance of the alteration of mud in foraminiferal tests to give glauconite. Murray and Renard observed transitions from yellowish-brown mud to glauconite, but believed it improbable that any glauconite was formed from mud in the free state, that is, mud which was not enclosed within foraminifera. Galliher explains the occurrence of glauconite within broken foraminiferal shells as being due to small flakes of biotite which have been sifted into foraminifera, and which have undergone considerable expansion during their transformation into glauconite. This hypothesis does not seem to explain satisfactorily numerous examples of coiled tests which are completely filled with glauconite, and which have both the outer walls and the inner walls separating the chambers, perfectly preserved. Galliher states that, in many cases, the expansion and growth of glauconite as it forms from biotite, causes the final product to assume shapes superficially resembling the casts of foraminifera.

Takahashi and Yoki (1929) have described stages in the formation of glauconite from grey, coprolitic mud. Under high magnification the grey mud is revealed as a heterogeneous complex consisting of extremely fine fragments of quartz and feldspar with a dark yellow or brownish, argillaceous matrix.

Biotite found in samples from the Janjukian of Victoria is mainly green, which renders difficult any investigation into its possible decomposition to green glauconite. Careful searching under high magnification has failed to reveal any grain with a core of biotite surrounded by a periphery of glauconite. Furthermore, no evidence of the "concertina" structure of Galliher has been seen. At the same time, some pale green glauconite grains with a mamillated surface, and with well-defined boundaries, resemble adjacent biotite flakes in shape. These pale green grains have a very low birefringence, and may perhaps have been derived from biotite. Thus although no direct evidence of the conversion of biotite to glauconite can be presented, it seems not impossible that a little at least of the glauconite may have come from this source.

Glauconite which is present as occasional, small, poorly defined patches which appear to grade imperceptibly into the surrounding pale, yellow-brown, argillaceous base, is probably not secondary after mica. The so-called argillaceous or muddy matrix is invariably difficult to resolve into its components under the microscope. It generally seems to be made up of yellow, brown or grey clay and finely-divided quartz, together with mica and possibly a little feldspar and carbonate. Minute



grains of pyrite and black iron ore may be abundant locally, and the whole may be stained to a varying degree by iron oxide. It should be borne in mind that the small glauconitic patches found in this base may have been formed initially within foraminifera, and may have been subsequently washed out of the tests or otherwise dispersed. Nevertheless, the lack of definition of some of the boundaries of the glauconite grains suggests that the mineral formed as a core which has slowly grown outward by some process of glauconitization. If so, it must be assumed that the argillaceous matrix itself was the precursor of the glauconite; the heterogeneous nature of much of the glauconite, which commonly contains small grains of mica, quartz and iron ore, strengthens this view.

Some glauconite, after concentration and separation from the crushed rock by panning, appears as grains which resemble very strongly the internal casts of foraminifera. When mounted in liquid and studied under the microscope, many grains show no evidence of a surrounding test wall. It is not certain what process has removed the wall. Miss Crespin has shown the writer several glauconite casts of foraminifera from the Upper Cretaceous of the north-west of Western Australia; some of these are partly surrounded by test walls which seem to be peeling off. If the walls have been removed during transportation along the sea floor, it is difficult to explain the perfectly preserved shapes of the glauconite surfaces. It is unlikely that the walls themselves have been glauconitized, for in some cases sections of pellets which have no outer wall contain clearly preserved inner walls which once separated the individual chambers of the foraminifera. It is not generally thought that calcareous test walls are prone to alteration into glauconite. The walls may, perhaps, have been pushed apart by the expansion of the argillaceous material during glauconitization, and may then have been removed; any such expansion must necessarily have been slight, for the final product is commonly a perfect internal cast of the test.

Ovoid grains without surrounding walls or internal subdividing walls may have been formed within the test of a single-chambered organism. On the other hand, in view of the apparently coprolitic nature of some of the mud in sample BR.4, it is possible that a little of this glauconite represents coprolite which has been transformed.

The origin of glauconite has been the subject of many interpretations. It has been described by different authors as a mineral which is secondary after mica, coprolitic pellets and mud enclosed within foraminifera. A little glauconite from the Janjukian type section of Victoria may, perhaps, have been derived from mica, but much has probably come from mud, both inside and possibly outside foraminifera. Where mud is converted to glauconite, it seems that an environment involving some form of imprisonment in the organic structure is very favourable, but perhaps not always necessary. It is of interest that Murray and Renard (1891) believed decaying organic matter enclosed within the tests played a large part in the transformation of mud to glauconite, and Schneider (1927) also postulated the necessity of an environment involving organic matter.

It is tentatively suggested that, on the basis of origin, at least two classes of glauconite may be recognized—glauconite formed from mica and glauconite formed from mud. It is further suggested that the refining or sieving undergone when mud is filtered into the chambers of foraminifera, or is passed through the digestive tracts of mud-eating organisms, together with the subsequent compaction it undergoes in each case, favours the formation of glauconite. The mineral has been described above occurring as small patches which have no obvious relationship to any organism. Thus, unless it can be demonstrated that the addition of some

organic compound is a necessary prerequisite to the formation of glauconite, there seems no conclusive reason to assume that free mud, suitably refined and compressed by some means during the normal process of slow sedimentation, can not be similarly transformed.

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